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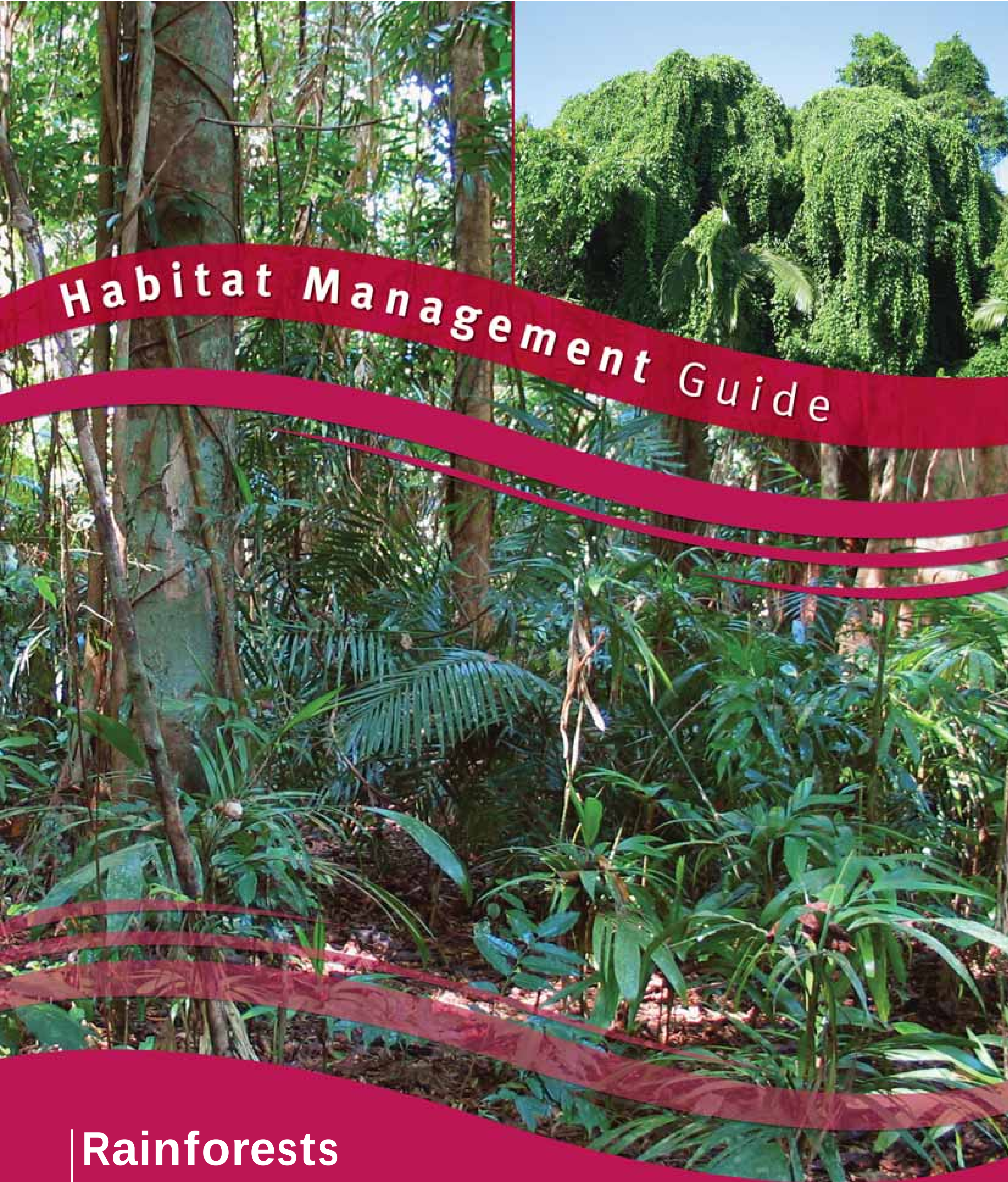

Habitat Management Guide

Rainforests

Ecological principles for the strategic management of weeds in rainforest habitats

CRC Weed management

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Front cover main: Un-invaded rainforest.
Front cover inset: The invasive *Dioscorea alata*.
Photos: A Ford CSIRO

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Contents

Summary

Weeds in rainforest habitats have traditionally been considered to impact only around edges and in highly disturbed areas. However more recently managers and researchers have discovered rainforest weeds can often occur in relatively intact rainforest habitat, greatly altering native community structure. Weed invasion is now becoming a major issue in the management and conservation of tropical forests.

A species-by-species approach to management becomes more difficult and costly with each new introduction, particularly as biological, ecological and spatial information is often sparse. The logistical difficulties involved in detecting, controlling and eradicating weeds in rainforest habitats means that resources are not available to deal with each species individually. Rather, a range of strategies is necessary for management, including focused management of high-risk single species, strategies that target suites of species, and strategies that target entire landscapes.

This publication focuses on the ecological processes that govern weed invasion in rainforest habitats and the ecological principles for strategically managing them so as to minimise weed introduction and spread.

The principles have three overarching goals:

1. reduce the threat of weeds to rainforest habitat
2. create resistant habitat
3. manage for resilient landscapes.

Un-invaded rainforest.
Photo: A Ford CSIRO

Introduction

Until recently, invasive plants were not considered a major threat to the conservation of tropical forests (Fine 2002). However, tropical forests are becoming increasingly fragmented and impacted by human activities with the result that weed invasion is growing as a major issue in their management and conservation. A species-by-species approach to management becomes more difficult and costly with each new introduction, particularly as the necessary biological, ecological and spatial information on which to base this management is often sparse.

Researchers and managers in Program 3 of the Weeds CRC have been engaged in research at the 'habitat-level' during the last few years. Many managers and researchers now recognise that a larger scale approach is needed to effectively control the spread and impacts of weed species in the long term.

Purpose of this document

The goal of this publication is to provide general **ecological principles** for strategic level management of weeds. It is *not* intended to provide 'operational' recommendations. This publication focuses on the ecology of weed species in rainforest habitats and the overall ecological role of weeds within a broad landscape context. The principles proposed are aimed at identifying and managing important ecological processes so as to minimise weed introduction and spread.

Tactical approaches to manage and control invasive species, such as spraying, burning and hand-pulling local invasions, without regard to the regional populations and distributions of these species, are unlikely to be effective or efficient over large scales, nor in the long term. This is because factors contributing to regional-scale persistence and spread are not addressed. Prioritising control of invasive populations based on their position in a regional context is likely to be the most effective strategy for controlling multiple species over the long term. This is not to suggest that tactical approaches are not important as it is at this level that individual plants are killed. Although many elements of the management approach suggested here represent tactical actions, successful management will be most likely when these actions are conducted within a landscape-level and regional strategic framework (see Section 3).

While the goal of this publication is to provide key messages for weed managers of rainforests, it is important for operational staff to understand and appreciate the broader context within which their control activities take place. Operational crews will have a unique perspective on patterns of weed invasion and processes creating those patterns in the field, consequently their feedback to managers is vital in designing effective management programs. Used alongside existing operational weed management programs, this publication may also assist in directing training modules and planning control activities.

Summary point

Currently management of invasions focuses on 'tactics'. Defined in a military context 'tactics' is 'the art of handling forces in battle or in the immediate presence of the enemy', while the large-scale management plan, or 'strategy', is the 'art of projecting and directing the larger movements and operations of a campaign'.

Clarifying terms

Habitat is usually defined in one of two ways:

1. as a species-specific characteristic—that is, the environment and other conditions that allow occupancy by a particular species
2. as a particular land-cover type.

For the purpose of this publication the second of these definitions is used. Rainforest habitat is defined further in Section 1.

The **landscapes** within which rainforest occurs are a complex mosaic of vegetation types, natural features, human uses, tenure and management scenarios.

The geographic management level referred to here is '**regional**'; that is, it spans across local council, natural resource management, catchment and even state boundaries.

Glossary of terms

Cyclone scrub	Repeated severe wind disturbance allows the persistence of vine towers on remaining trees resulting in this distinctive vegetation type
Delimit	To find and determine the spatial extent
Early successional species	Usually fast-growing species that require light for establishment and appear shortly after disturbance—also called 'pioneer' species
Ecosystem services	Renewable resources such as clean air and water supplies that humans derive from functional ecosystems
Ecotone	The transition zone between two adjacent ecological communities or habitat types
Epiphyte	An organism that grows on or attaches to another plant: eg, orchids and ferns are common epiphytes in tropical rainforest
Frugivore	A fruit-eating animal; in Australia most frugivores are birds or bats
Life-forms	A way of classifying a plant according to its above-ground structure eg tree, shrub, herb, grass
Matrix	The intervening habitat surrounding rainforest patches; the matrix may consist of natural (eg other types of forest or grassland) or modified (eg urban or agricultural areas) habitat
Monoculture	Complete dominance by one species of a particular area (eg horticulture, pond apple)
Mutualism	An association between organisms of two different species in which each member benefits
Naturalised plants	Introduced plants that have established self-perpetuating populations in their introduced range
Niche	The set of characteristics that define the environmental conditions under which a particular species is found and its role in an ecological community
Propagule pressure	The term 'propagule' in the context of invasions ecology refers to any structure (eg the seed or vegetative part) of a plant that disperses. Propagule pressure incorporates the number of propagules that are dispersed and the number of dispersal events. As the number of propagules released and / or the number of release events increases, propagule pressure also increases.
Recruitment	The addition of new individuals to a population or to a particular life stage in the population eg seedlings are new recruits to the population
Seed dispersal	The process by which a seed moves from its maternal plant to the site where it establishes or dies
Seed shadow	The spatial pattern in which a plant's seed crop is distributed around it
Sleeper weed	Invasive plants that currently occur in low numbers but have the potential to increase their population size dramatically given the right conditions
Succession	A process of vegetation change including that which occurs following disturbance; usually defined as including transitions between different plant community types

1. Rainforests of Australia

In Australia, rainforests are scattered across cool temperate, warm temperate, sub-tropical and tropical areas of Queensland, New South Wales, Victoria and Tasmania. Small patches are also found in north coastal Northern Territory and the Kimberley region of Western Australia (NLWRA 2001). Rainforests occur from sea level to high altitudes and normally within 100 km of the coast. They mostly occur in areas receiving an average annual rainfall of more than 1200 mm, or in areas with lower rainfall but protection from high evaporation rates (NLWRA 2001).

In this publication the emphasis is placed on sub-tropical and tropical rainforests of eastern Australia, primarily those found in Queensland and New South Wales (see Figure 1). The drier, semi-deciduous vine thickets, like those in the Brigalow Belt, or monsoonal vine thickets scattered over northern Australia, are not targeted in this document. However some ecological processes may be similar in these communities and some of the management principals will apply to them.

Distribution

Rainforests were among the earliest Australian native vegetation communities to be exploited for timber and cleared for agriculture. Logging of the wet tropical rainforests started in the 1870s and most of the area was available for selective removal of commercial timber species until 1988. Rainforests have also been subjected to destruction or fragmentation for industry development including housing, access routes and transport corridors (NLWRA 2001; Werren 2003). In north Queensland, lowland rainforests have particularly suffered from fragmentation and only small areas now exist. However, large areas of escarpment and highland rainforest communities are intact and can be found on steep or rugged terrain (Goosem 2003).

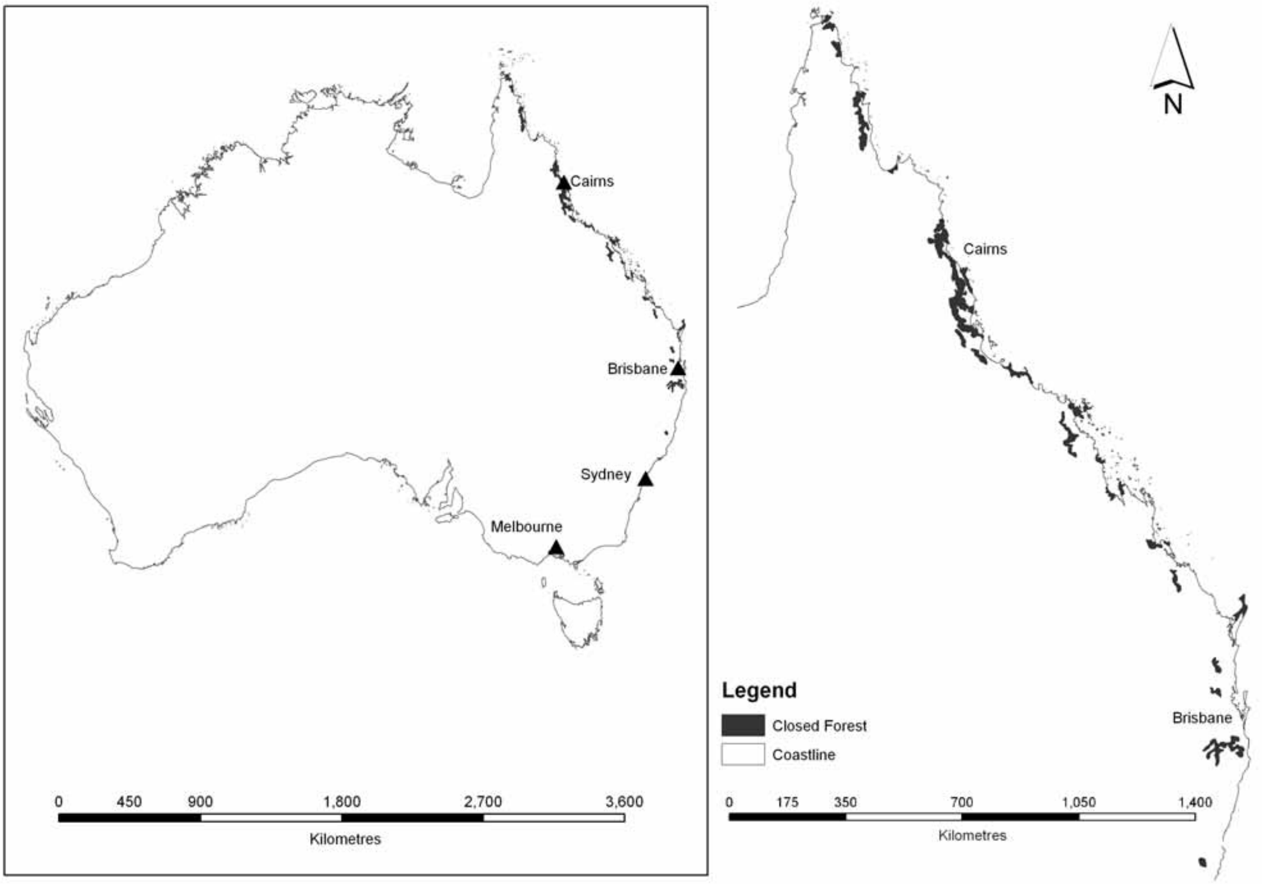


Figure 1: The geographical distribution of eastern Australian sub-tropical and tropical rainforests, 1980. Present vegetation at 1:5,000,000.
Credit: Geosciences Australia

The Wet Tropics rainforests

The largest area of remaining rainforest in Australia is located in the Wet Tropics region of north Queensland (Werren 2003). The Wet Tropics region contains tropical complex mesophyll vine forests, encompassing a unique mixture of widespread species, a high diversity of plant groups exhibiting primitive features and a significant number of local endemics (Metcalfe and Ford 2008). This richness has been acknowledged internationally by the inscription of The Wet Tropics of Queensland World Heritage Area (WTQWHA) on the World Heritage List in 1988. Further, in 2007 the WTQWHA was inscribed on the National Heritage List for possessing outstanding heritage value.

The Wet Tropics bioregion contains considerable topographic diversity and high rainfall gradients. Temperature and rainfall are the two major climatic factors that influence plant distribution and floristic assemblage. However soil characteristics (substrate and parent geology) also have significant effects on floristic composition (Metcalfe and Ford 2008). High humidity and ground water levels create ideal conditions for communities of ferns, epiphytes and lithophytes. Seasonal impacts from prevailing winds, including high wind speeds during tropical cyclones, high rainfall events and storm surges also affect plant distribution and can result in heavy vine growth dominating at the expense of other vegetation. The effects of wind and rain are most apparent on the coastal ranges where repeated disturbances allow the persistence of vine towers on remaining trees resulting in a distinctive vegetation type known as ‘cyclone scrub’ (Metcalfe and Ford 2008).

Sub-tropical rainforests

Sub-tropical rainforests are found in northern New South Wales and southern Queensland. They are typically closed-canopy forests with woody vines, epiphytes, palms and strangler figs present along with a high diversity (10 to 60 species) of canopy species (Webb et al 1984). A number of sub-tropical rainforest types have been classified, with the most common ones being the complex notophyll vine forest, microphyll vine forest and semi-evergreen notophyll vine thickets (Webb 1968). The natural distribution of these rainforests is patchy, dependent on soil type, aspect and rainfall, with closed-canopy rainforest set within a matrix of open forest and woodland from sea level to approximately 900 m (Webb 1968). Soils are typically fertile, derived from rich parent materials (basalts and rich shales) with annual rainfall typically 1300 mm or more.

Extensive clearing of sub-tropical rainforests occurred after European settlement and only a small portion of the original rainforest now remains; for example only 1 % of one of the largest sub-tropical rainforest areas in northern New South Wales, known as the Big Scrub (original estimated extent of 75,000 ha) still remains. Although a large portion of the remaining sub-tropical rainforest is protected within the Gondwana Rainforests of Australia World Heritage Area, the remaining rainforest largely exists as fragmented patches that are vulnerable to weed invasion. Regrowth or expansion of patches can be arrested by weed invasion eg lantana (*Lantana camara*) (Hopkins et al 1976), but in some areas careful management of weedy regrowth is required as some invasive species, such as camphor laurel (*Cinnamomum camphora*) provide habitat that supports vertebrate frugivores, that in turn facilitate the recruitment of native forest species by dispersing both fleshy-fruited native and exotic species (Neilan et al 2006).

Diversity, density and structure

The term ‘rainforest’ encompasses many different structural types of forest from lush, epiphyte-rich communities, to semi-deciduous forest and cyclone-scrub (Metcalfe and Ford 2008). However, all rainforest types have several characteristics in common. Rainforests are characterised by high species diversity compared with other habitats. High diversity generally means that most species occur at low densities. Tropical tree inventories typically demonstrate that even the most abundant species are not very abundant in absolute terms, while rare species are extremely rare. Rainforests are also characterised by a relatively large proportion of species that can tolerate shady conditions.

A small proportion of rainforest species seem to require a large gap to grow in (pioneer species), though many species require or prefer some level of canopy opening for germination or growth (Denslow 1987).

Rainforests are typically evergreen, though deciduous and semi-deciduous species do occur, conifers also occur but not commonly, tree ferns are abundant as are cycads and epiphytes. Herbs and grasses are sparse in the understorey except in gaps. The Wet Tropics rainforests have a high level of endemism with nearly 30 % of species that do not occur anywhere in the world outside the region, and over 60 % of the flora occurs only in Australia (Metcalfe and Ford 2008).

Significant weeds of rainforests

There have been numerous attempts to list and classify the seriousness of the threat posed by introduced species into rainforests. Depending on their perspective and intent, these different lists describe weeds that are in various stages of invasion, have more or less serious potential impacts, are suitable for eradication as opposed to containment or control, are major problem weeds in other countries or are 'sleeper' weeds. There are lists for sub-tropical and tropical areas including the Wet Tropics Weed List and Ranked Wet Tropics Weeds (Werren 2003).

Of primary interest to managers are the listings identifying species for management and funding priority such as Weeds of National Significance (WoNS) and Alert weeds.

Weeds of National Significance

Species are assessed against several criteria including their invasiveness, impacts, potential for spread and socio-economic and environmental values. The 20 WoNS are considered to require long-term, strategically coordinated action at the national level in order to minimise their economic, social and environmental impact. Several of these WoNS species occur in and around rainforest landscapes; lantana (*Lantana camara*), pond apple (*Annona glabra*) and the water weeds hymenachne (*Hymenachne amplexicaulis*) and cabomba (*Cabomba* spp).

Several other lists complement the WoNS list including the national environmental Alert list and the Sleeper weeds list (see box). The Alert list contains 28 species, including the tropical weeds Siam weed (*Chromolaena odorata*), laurel clock vine (*Thunbergia laurifolia*) and praxelis (*Praxelis clematidea*).

Land Protection (Pest and Stock Route Management) Act 2002

This Queensland Act lists three categories of 'declared' plants; Class 1, 2 and 3. Depending on which Class a species is assigned to, a range of statutory restrictions are activated. These may include restrictions on sale, introduction, possession or transport of the species. In the case of Class 1 and 2 declared pests the declaration also imposes a legal requirement on all landowners to take reasonable steps to keep their land free of these pests.

Declared Class 1 weeds occurring in and around rainforest landscapes include:

- *Clidemia hirta* (Koster's curse)
- *Miconia calvescens*, *M. racemosa* and *M. nervosa*
- *Mikania* species
- *Chromolaena odorata* (Siam weed)
- *Cecropia* species
- *Thunbergia annua*, *T. fragrans* and *T. laurifolia*
- *Limnocharis flava* (Limnocharis).

The full list of declared Class 1, 2 and 3 weeds can be seen on the Queensland Government web page associated with the Act (currently www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/4790_7005_ENA_HTML.htm).

Sleeper weeds

Sleeper weeds are usually defined as invasive plants that currently occur in low numbers but have the potential to increase their population size dramatically given the right conditions.

Five situations or characteristics that may restrict sleeper weeds are:

1. a current limited ability to adapt to the local environment
2. spread limited by suitable habitat
3. limited opportunities to colonise new habitat
4. low population growth rates (eg long times to maturity)
5. an absence of mutualists (eg pollinators).

Additionally, species may be wrongly perceived to be not invasive (Grice and Ainsworth 2003).

There are many examples of species that occurred in Australia for long periods before their populations spread to the point of being considered invasive. Brillantaisia (*Brillantaisia lamium*) is currently listed as a Class 4 sleeper weed (species for which eradication is desirable but probably not feasible) identified by the Bureau of Rural Sciences, in consultation with the Australian Weeds Committee. It occurs in areas adjacent to rainforest in north Queensland and is somewhat shade-tolerant so it may colonise gaps in intact rainforest and form dense mats, competing with native vegetation.

National eradication programs in the tropics

Some of the exotic weeds occurring in Australia have the potential to seriously impact at the national level on the country's primary industries, trade, the economy and the environment. The elimination from Australia of some of these weeds is considered justified and feasible, and they are subject to national eradication programs.

The four tropical weeds eradication program

In 2001 a national, cost-sharing, weed eradication program commenced focussing on four Class 1 genera, covering six species. The species are *Clidemia hirta* (L.) D.Don; *Limnocharis flava* (L.) Buchenau; *Miconia calvescens* DC.; *Miconia nervosa* Triana; *Miconia racemosa* (Aubl.) DC. and *Mikania micrantha* (Kunth).

National Siam weed eradication program

This program commenced in 1995 to eradicate Siam weed (*Chromolaena odorata*) from Queensland where it is currently infesting areas in the Far North. It is recognised as one of the world's worst tropical weeds.

Life-forms of tropical and sub-tropical weeds

The diversity of plant species in rainforests means that for convenience, categories of species are often considered rather than all the individual species. The nature of this categorisation varies. For example, rainforest plants can be categorised into a variety of life-forms including herbs, shrubs, vines and trees based primarily on their structure. These life-form categories provide an imperfect but useful summary of plant ecological and invasive attributes and consequently provide some guidance on likely distributions and appropriate management responses.

While invasive herbs and grasses do not generally dominate intact rainforest habitat, herbs such as thickhead (*Crassocephalum crepidioides*), bluetop (*Ageratum conyzoides* ssp. *conyzoides*) and Singapore daisy (*Sphagneticola trilobata*) are common invaders of rainforest edges or in heavily disturbed areas. Grasses are not common invaders of rainforests but persist readily along the edges. Invasive grasses may act to increase fire frequency and intensity at the margin of rainforests promoting a progressive retreat of the rainforest margin.

Vines are an important element of the structure of sub-tropical and tropical rainforests (NLWRA 2001). In south-eastern and northern New South Wales sub-tropical rainforests, 70 % of the exotic species are vines (ANPWS 1991). Most exotic vines were introduced for ornamental purposes and the majority of these originate from South America.

Vines have the capacity to smother all layers of a rainforest from the canopy to the forest floor. Occurring in high or low light conditions, vines can smother disturbed and undisturbed forest, reduce light levels and alter microclimate conditions of the understorey (ANPWS 1991). Vines like thunbergia (*Thunbergia grandiflora*) are fast growing and can reduce healthy rainforests to a stand of vine-draped poles within 1 to 2 decades (ANPWS 1991; Setter and Vitelli 2003). Problem vines in the sub-tropics include cat's claw creeper (*Macfadyena unguis-cati*), Madeira vine (*Anredera cordifolia*), balloon vine (*Cardiospermum grandiflorum*), *Asparagus* spp., moth vine (*Araujia sericifera*) and *Passiflora* spp.



Vines have the capacity to smother all layers of a rainforest. L—R: the invasive water yam (*Dioscorea alata*) smothering native vegetation in a rainforest fragment near Tully, North Queensland; the sub-tropical weeds balloon vine; and cat's claw creeper.
Photos: A Ford CSIRO; G Vivian-Smith QDPI&F and M Trevino QDPI&F

Matchbox bean vine towers along riparian vegetation.
Photo: A Ford CSIRO

An aggressive native, Captain Cook vine (*Merremia peltata*)

Rainforests of the Wet Tropics are seasonally affected by winds, rainfall events and storm surges. The impacts of this can be observed through canopy disturbance, vine growth and / or cyclone scrub (Metcalfe and Ford 2008). Captain Cook vine is a native plant that behaves aggressively on rainforest edges by inhibiting the regeneration of other native species. It is considered 'weedy' due to its massive increase in abundance at artificial rainforest edges adjacent to agricultural lands and infrastructure corridors. Other native vines such as the matchbox bean (*Entada rheedii*) display similar tendencies.

Many researchers (Binggeli et al 1998; Setter et al 2002) note the importance of woody life-forms and their potential to damage and invade tropical and sub-tropical rainforests. Introduced tree and shrub species that have become a problem in tropical rainforest include pond apple (*Annona glabra*), harungana (*Harungana madagascariensis*) and miconia (*Miconia calvescens*). In the sub-tropics, introduced tree weeds include camphor laurel (*Cinnamomum camphora*), large-leaved privet (*Ligustrum lucidum*) and small-leaved privet (*L. sinensis*) (ANPWS 1991). The most successful invasive trees are often ornamental or forestry escapees (Fine 2002).

Murraya (*Murraya paniculata*): popular ornamental shrub, but potential rainforest weed?

Murraya (*Murraya paniculata* cv *exotica*) is a popular hedging plant that produces fleshy, orange-red fruits. Indications are that the species has every chance of becoming a bird-dispersed environmental weed in sub-tropical eastern Australia (White et al 2006). Research has shown that figbirds (*Sphecotheres viridis*) can feed on murraya fruits for 6 months of the year passing seeds through their guts with germination rates of 75 %. Murraya is also able to recruit readily under the kinds of conditions found in rainforest habitats in the Brisbane region and field surveys indicated that murraya plants were present in low densities at all suburban rainforest sites surveyed, with some already reproductive.

Functional traits and niche space

Some plant characteristics (or functional traits) can increase the chance of a plant becoming weedy. Functional groups represent sets of species that share similar traits (such as life-form, seed type, dispersal mode, shade tolerance etc) and so exhibit similar responses to environmental conditions or have similar effects on the dominant ecosystem processes. Common traits amongst native rainforest species are that they tend to tolerate shade well, a large proportion of them have fleshy fruits, trees are abundant and herbs and grasses are uncommon.

A species' niche represents the full range of physical and biological conditions under which it exists. This can include parameters related to the species' physical structure and space requirements as well as those related to its habitat and how it responds to environmental change. It is generally considered that due to high species diversity in rainforest, all the available niche space is utilised, making it difficult for invading species to establish successfully. This is why disturbance is considered such a critical factor in promoting invasions in rainforests: disturbance creates opportunities for exotic species to claim space and resources that become available.

One invasions theory suggests that exotic species with traits that are absent or uncommon in the native rainforest flora may become invasive because they fill a 'vacant' niche. Indeed, most invasive species that impact rainforest habitat are intolerant of shade, an uncommon trait in the native flora, and are herbs or shrubs; trees are usually the most common life-form among native species (see Mabi Forest and vacant niches).

Mabi Forest and vacant niches

The Mabi Forest (complex notophyll vine forest—type 5b) on the Atherton Tableland in north Queensland is listed as a critically endangered ecological community under Commonwealth legislation (Metcalfe and Ford 2008). It is currently spread over remnant patches containing a total area of only 3.2 % of its past extent (Goosem 2003).

Murphy et al (2006) identified differences in functional characteristics between native and invasive species in the Mabi Forest. The research showed that if an invading species is of a particular functional group not well represented within the native community, there is an increased likelihood of successful invasion. For example, rare native functional groups in the Mabi Forest include shade-intolerant and partly-tolerant species, particularly those with dry or large fleshy fruits. The most common exotic species in the Mabi Forest all have small, fleshy fruit which is a common trait in the native flora, allowing them to exploit the full range of bird dispersers; but they do not tolerate full shade (*Solanum seaforthianum*, *S. mauritianum*, *Lantana camara* and *Rivina humilis*). They therefore are able to disperse easily to disturbed areas but still fill a niche which is rare or vacant in the native flora, ie shade intolerant, and so have the capacity to out-compete native species during regeneration after disturbance.

Murraya seedling recruiting in rainforest.
Photo: E White DPI&F

Weeds as a homogenising factor in landscapes

Homogenisation in ecological communities is defined as increasing similarity of species composition among a set of communities over time.

Two distinct processes drive homogenisation:

1. the extinction of resident native species (losers)
2. the invasion of exotic species (winners).

The replacement of native ecological specialists with widespread invasive species tends to homogenise otherwise diverse communities resulting in communities within a region becoming more similar to one another.

Homogenisation might also play a significant role in increasing the rate of spread of invasive species and decreasing community resistance to invasion. Communities with high species diversity, like rainforests, are thought to resist invasion more readily because they utilise the available resources (eg space, light, soil nutrients etc) more fully. The loss of ecological specialists from communities creates opportunities for other species to capture resources and may encourage further invasion. This can result in what is called 'invasional meltdown,' where invasive species in the system directly or indirectly facilitate invasion by other species.

Anzac flower (*Montanoa hibiscifolia*) retarding succession in a gap in rainforest at Crater Lakes National Park, Queensland.
Photo: D Metcalfe CSIRO

Disturbance and opportunities for weed invasion

Disturbance is a natural phenomenon in rainforests and is considered to be a key process in the maintenance of species diversity because it creates opportunities for species to claim previously utilised space and resources. The type, extent and frequency of disturbance can modify conditions in a way that promotes weed invasion, with potential for change in temperature, humidity and / or light levels, and thus the susceptibility of the site to invasion.

Invasives as 'drivers' or 'passengers' of disturbance

Do invasive species 'drive' community change in native communities or are they 'passengers' to other types of disturbance? The 'driver' model suggests that an invasive species is directly responsible for its own dominance because it is a superior competitor, while the 'passenger' model suggests that invasives are passengers to other types of disturbance.

Different invasive species, including those of tropical systems, probably differ in terms of whether they are drivers or passengers, and some species appear to play different roles in different contexts. Invasives of rainforest rarely tolerate shade so at least some kind of minor disturbance resulting in an opening of the canopy is usually necessary for their establishment. For example, *Lantana camara* requires light to colonise, so initially it may be considered a 'passenger' to some other kind of disturbance, but it may then competitively dominate native species, 'driving' subsequent community change.

Natural disturbance

Natural disturbances caused by tree-fall gaps, fire, cyclones and landslides often provide suitable environments for populations of invasive plants (Lepš et al 2002; Baret et al 2005). Seasonal rainfall and associated flooding can result in high-velocity flows and erosion whilst large-scale disturbance events such as cyclones can cause extensive defoliation, loss of major branches and multiple tree falls.

Windthrown trees, treefalls and large broken branches create a mosaic of light gaps and opportunities for invaders in tropical forests (Sanford et al 1986). A natural gap's size may be an important determinant of which species can successfully colonise it. Small gaps may only have a marginally improved light regime that is unsuitable for shade-intolerant species and so shade-tolerant species may be favoured (Hartshorn 1980). Clumped patterns of disturbance may be common in tropical forests with gap clusters sometimes formed by multiple treefalls during disturbance events.

Large disturbed areas may be more susceptible to invasion because seeds, by chance, are more likely to arrive in them than they are in small-scale disturbances. Areas affected by large-scale disturbances such as cyclones may also have a slower recovery rate (Boose et al 2004), making available a wider window of opportunity, as well as a wider range of opportunities, for colonisation by invasive plants. Large-scale unpredictable disturbance events such as cyclones present many opportunities for weed invasion; they cause massive disturbance over large areas (Murphy et al 2008) and wind and flood waters may carry seeds over long distances. If the number or intensity of cyclones increases due to changes in climate, opportunities for plant invasions over large scales will also increase.

Cyclone disturbance to North Queensland rainforest

The recruitment of plants (both introduced and native) after a natural disturbance event such as a cyclone, will determine long-term habitat structure and composition.

Some of the most recent research into tropical cyclones and invasive responses in rainforests has occurred since severe Tropical Cyclone Larry (category 4 cyclone with an estimated central pressure of 915 hPa), crossed the coast near Innisfail in north Queensland, on 20 March 2006, travelling due west. Rainforest affected include fragmented remnants of coastal lowland floodplains, the largely intact extensive forests of the coastal range (Bartle Frere and Bellenden Ker Mountains), and fragmented rainforest on the Atherton Tableland (Metcalfe et al 2008).

The impact of Cyclone Larry on the weed flora was largely through opening the canopy and permitting high levels of light to reach the forest floor. This provided ideal growing conditions for transient weed species (eg the daisy family, Asteraceae) that could spread highly mobile, wind-dispersed seeds into high light conditions (Murphy et al 2008). Weed diversity and abundance following the cyclone was greatest in the most disturbed sites (Metcalfe et al 2008; Murphy et al 2008).

The slower-growing woody weed species such as miconia, *Solanum* species and giant bramble (*Rubus alceifolius*) are much more likely than the weedy herbs to persist and become firmly established in the recovering understorey (Murphy et al 2008). This has the potential to impact rainforest composition over much longer periods of time. An important point to note for weed managers is how weed recruitment was suppressed in some locations by dense debris piles or the aggressive regeneration of native species (Metcalfe et al 2008).

Damage from Cyclone Larry near El Arish, Queensland.
Photo: T Sydes Biosecurity Queensland

Pig damage in a rainforest understorey.
Photo: D Metcalfe CSIRO

Disease and pests

Disturbance may also be created by invasive species themselves. Pest disturbance to rainforests can occur from the activity of introduced animals (eg feral pig *Sus scrofa*) or the effects of disease (eg root-rot fungus *Phytophthora cinnamomi*). For example, *Phytophthora* was first recorded in north Queensland rainforests in 1975 and was associated with patches of defoliation, crown dieback and plant death (Gadek 1999). In areas showing symptoms of *Phytophthora*, opportunities for invasion arise with an opening of the canopy, disruption to habitat structure or the death / reduced health of native plants. Introduced species that are resistant to *Phytophthora* and require light are then given opportunity for entry, establishment and spread within a rainforest.

Introduced animal pests can disperse weed seed into new areas and over long distances. An example of this is the feral pig which helps pond apple to proliferate in areas where it currently occurs, by dispersing its seed, destroying existing vegetation and creating ideal conditions for germination with soil disturbance (Setter et al 2002). Germination of defeacated seed is assisted by warm, moist, high nutrient conditions. Setter et al (2002) noted that the feral pig could disperse pond apple seed up to 10 km though only about 2 % of seeds survive gut passage.

Human disturbance

Human disturbance occurs during the construction of roads, clearcuts, logging of areas and development of agricultural crops as well as from urban development and industry. Extreme disturbance to eastern Australian rainforests has occurred since European colonisation with large areas being cleared and landscapes fragmented. The area now occupied by rainforests in Australia overall is likely only about a quarter of what was present at the time of European settlement 200 years ago. The Wet Tropics has faired better and probably still contains more than 75 % of the original rainforest vegetation. However, the rainforest of the lowlands and the more fertile upland areas have been hardest hit by European disturbance, with some communities at less than 10 % of their former extent.

Planned disturbances, such as those for power easements, roads, logging etc, typically are different from natural disturbances. Perhaps the most significant difference is that planned disturbances often disrupt the soil profile over a large scale. Examples of disturbances that have been left to regenerate naturally are abundant on our landscape. These areas usually contain the highest richness and abundance of invaders (Hobbs 2001; Hansen and Clevenger 2005). Service corridors (walking tracks, power-line clearings and roads) act as reservoirs for weeds and also as the primary conduits for weed spread. High concentrations of weeds are observed in transport corridors (Panetta and Hopkins 1991; Hansen and Clevenger 2005) and traffic of all kinds aids in the dispersal of weeds into surrounding habitat by causing air turbulence and by acting as vectors for spread of seeds and vegetative plant parts (Hansen and Clevenger 2005).

Planned disturbances are now often accompanied by revegetation plans that include minimising disturbance to, and reconstruction of, the soil profile after disturbance. They also incorporate hygiene protocols to minimise weed seed spread. Some research has shown that species composition after disturbance is somewhat predictable from the pre-disturbance seedbank (van der Valk and Pederson 1989) and so sampling of the pre-disturbance seedbank can provide insight into whether exotics might become abundant at a site.

Dispersal

Dispersal is one of the most important processes determining invasion success. Dispersal distances for a given species depend on the type, number and frequency of dispersal mechanisms.

Seed shadows and dispersal curves

The pattern (shape and scale) of dispersal is known as a seed shadow and varies depending on:

- fruit characteristics (fleshy, dry, protected, size, shape)
- seed characteristics (shape, size, obtrusions)
- the dispersal vector(s) (social behaviour, fruit-handling techniques, gut-passage rates, patterns and distances of movement through time, prevailing winds, direction of water flow)
- plant-disperser interactions
- habitat structure within the landscape including landscape patchiness (Buckley et al 2006; Stansbury and Vivian-Smith 2003; Westcott and Dennis 2003; Westcott et al 2005; White et al 2004).

Seed shadows usually demonstrate that most seed disperses only relatively short distances from the parent plant with a smaller proportion dispersing over longer distances. In general terms the short-distance dispersal can be considered as contributing to increasing the local densities and spread of the weed. The rarer long-distance component of dispersal is the hardest to measure but is the most influential in determining the rate and pattern of spread across the landscape. A single seed dispersed a long distance may result in a new infestation far from the established infestation and consequently may have serious implications for management.

Summary point

Understanding the outcome of dispersal is critical for predicting the potential rate and extent of spread of invasive species. The spatial scale of dispersal, ie how far seeds are dispersed, determines the spatial scale at which management activities should be conducted.

Generating dispersal curves and seed shadows for fleshy-fruited invasive species

Observing frugivores removing seed and dispersing it from potentially highly invasive species in the Australian wet tropics, particularly those subject to eradication programs (such as miconia), is clearly not an option.

However, dispersal curves can be assembled based upon two integral components:

1. native plant species with similar fruit characteristics which can be observed for fruit removal
2. movement patterns of those frugivores likely to occur within an infestation.

The distance a disperser moves seed is a function of how long it retains the seed and how far it travels from the point at which the seed was consumed. The former measurement is usually obtained during captive feeding trials and the latter using continuous radio-telemetry of animals in the field. The product of these two distributions represents the dispersal curve for that particular species.

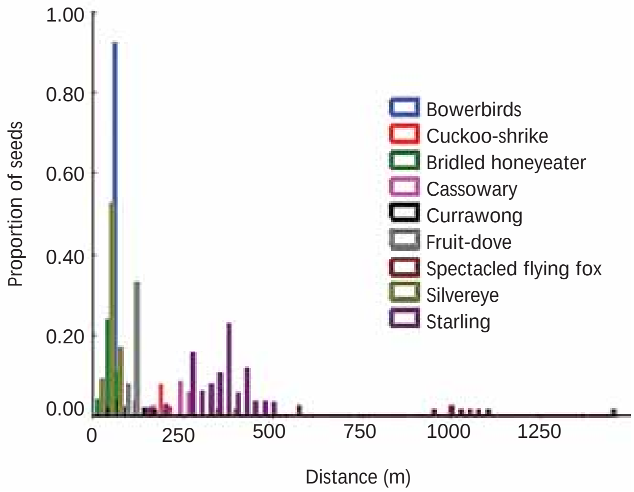


Figure 2: A dispersal curve.
Credit: D Westcott CSIRO

Frugivore dispersal

A large proportion of plant species in Australian tropical rainforest habitats have fleshy fruits and are therefore considered to be primarily animal dispersed. The frugivores that disperse these fruits (see Frugivorous birds and generalised dispersal systems) are mainly birds but also include a variety of mammals and some other vertebrates and even some insects. In the Wet Tropics, approximately 70 frugivore species, primarily birds, are recognised as 'regular' dispersers and many others, including fish, turtles and ants (Westcott et al 2008a) probably play an occasional role. The pattern in which these animals deposit seeds varies according to the number of seeds dropped in each 'deposition' (eg clumped for cassowaries which produce large dung piles with hundreds of seeds in them or scattered for small birds whose droppings may contain only a single or a few seeds). When deposition is clumped there is the possibility that multiple species and a potential suite of introduced plants could establish together (Stansbury and Vivian-Smith 2003). Similarly, how depositions are distributed through the environment can vary within and between dispersers. When animals tend to move towards and spend time in particular locations, eg a nest, feeding tree or vegetation type, dispersal is directed towards those areas. In contrast when animals move generally and deposition occurs at any time, seeds are dispersed randomly within the environment. Because of the distance involved in bird movement and greater time in the air, opportunities for invasion by fleshy-fruited weed species are often enhanced (Werren 2003).

Aspects of fruit morphology such as seed size, colour, nutritional quality, fruit crop size, presentation and accessibility affect the probability and quality of seed dispersal (Dennis and Westcott 2007). Some characteristics of fruit timing also enhance dispersal opportunities for invasive species. For example, where fruit is present on the plant for long periods this increases opportunities for bird dispersal, and fruiting when native fruit production is limited increases the probability that an invasive fruit will be consumed by frugivores (Gosper et al 2005).

Summary point

Seed dispersal processes for fleshy-fruited species appear to involve loose, and even opportunistic, groupings of animals that consume generalised classes of fruits. These loose relationships between plants and dispersers mean a weed species with fleshy fruits will find a large and enthusiastic suite of potential dispersers ready to consume and disperse its fruits in almost any environment.

Frugivorous birds and generalised dispersal systems

A survey conducted in south-east Queensland and northern New South Wales found that fruit from one weed species could be consumed by up to 20 different frugivorous bird species (Stansbury and Vivian-Smith 2003). The results also showed that, of the traits studied, fruit size was most important in determining fruit choice by birds, with plants with smaller fruits tending to have more bird dispersers.

Stansbury and Vivian-Smith (2003) highlight that dispersal is also likely to be most dependent on fruit-handling techniques, foraging habits and territorial / migratory movement. Generalised dispersal systems tend to involve fruits with many small seeds that are often attractive to a large range of opportunistic frugivores (Stansbury and Vivian-Smith 2003). Plants that have generalised modes of dispersal are more likely to contribute high numbers of seeds to a particular community and are likely to be more invasive than those relying on specialist dispersal agents (Fine 2002; Stansbury and Vivian-Smith 2003).

Metallic starlings consume a wide variety of rainforest fruits.
Photo: A McKeown CSIRO

'Ideal' weeds. *Miconia racemosa* (a Class 1 weed in Queensland) has small, fleshy fruit that is attractive to frugivores, contains many tiny seeds and can regenerate from vegetative material such as leaves.
Photo: D Hardesty CSIRO

The fruits of some weeds such as camphor laurel can be consumed by many different frugivores, in this case more than 20 reported species.
Photo: C Gosper

Water and wind dispersal

Environmental factors also play a role in plant dispersal and can include wind, water and soil. Wind can remove seeds or fruit from the parent plant under intact rainforest canopies to allow short-distance dispersal. However cleared patches of land create significant air movement, and transport corridors can act as funnels for seeds such that wind-dispersed seeds, like those in the Asteraceae family, can travel long distances (Goosem 2003; Metcalfe et al 2008). Rainforest weeds that are well adapted for wind dispersal include cat's claw creeper (*Macfadyena unguis-cati*) with its thin papery seeds, and moth vine (*Araujia sericifera*) which has seeds with a silky plume or 'coma'. Moth vine seeds can be carried long distances by updrafts, resulting in many infestations that occur as small, isolated patches at the top of mountain ranges (Vivian-Smith pers obs).

Seeds that fall into water are moved along with the current and raindrop impact on the fruiting body can cause expulsion of seed (Westcott and Dennis 2003). Additionally, rapid and wide-spread dispersal can take place where seasonal flooding occurs. Some invasive species in tropical regions show capacity to spread over long distances via water movement. For example, the invasive vine species; cat's claw creeper, balloon vine (*Cardiospermum grandifolium*) and moth vine (*Araujia sericifera*) have lengthy buoyancy periods indicating a strong capacity for fruits to be spread downstream (Vivian-Smith and Panetta 2002; 2005). Current research into the viability of pond apple seeds in marine environments suggests that fruit and seeds are buoyant and can survive very long periods in both salt and fresh water (Setter et al 2008). Floating plant parts and plants that fragment readily, such as Madeira vine (*Anredera cordifolia*), facilitate efficient dispersal in flowing water and can significantly increase weed distribution during seasonal flooding. Plants generally establish in areas of slow river current, and in particular pond apple poses a significant threat to disturbed (flood prone) ecosystems including high water marks in coastal riparian and rainforest communities. For species such as pond apple, which can survive salt water, coastal currents can also facilitate spread over large distances to locations that might not be accessible through other means (Holloway 2004).

Summary point

For information regarding weed management of riparian areas refer to the companion *Habitat management guide—Weed management in riparian areas: south-eastern Australia*.

Human-mediated dispersal

Weeds are commonly spread with the help of humans. An analysis of potential dispersal vectors of all noxious weeds in Australia in 1995 revealed that humans contributed to the dispersal of nearly 90 % of these species with 21 % dispersed by humans alone (Panetta and Scanlon 1995). Dispersal through vectors such as contaminated grain, soil and gravel, and stock, machinery and vehicle movement are common. The sale and exchange of garden products and landscaping materials is also responsible for the spread of many weeds in the tropics. Roads are a particularly important pathway for weed movement and spread since weed seeds may be moved over long distances and because roadsides often provide very good conditions for weed establishment.

Long-distance dispersal, sources and satellites

When dispersal incorporates long- and short-distance components, it is the long-distance component (which is the most difficult to measure) that most strongly influences the rate of spread, even when long-distance dispersal is rare. Long-distance dispersal spectra no longer necessarily reflect an invader's adaptations for dispersal (Hulme 2003). It is unlikely that even the most sophisticated spread models will include the complexity of all dispersal, especially since chance events appear to be common in very long-distance dispersal (Hulme 2003). For example, human-mediated dispersal, which includes such diverse but influential processes as horticultural trends and social networks, and the continuing expansion of road infrastructure and their pattern of usage, is particularly difficult to describe and predict.

The early stages of invasion are often characterised by one or a few patches that are much larger than all the others and, because these weed patches are large, they are most easily detected. These are usually continually replenished by short-distance seed dispersal. Long-distance dispersal is primarily responsible for the establishment of new 'satellite' populations in tropical forest. These satellite individuals may form small populations that eventually go extinct or they may be initially replenished from the main source population and eventually become self-sustaining. A 'blinking lights' analogy is often used to describe this formation of new populations (see Figure 3).

Summary point

Because long-distance dispersal is common in tropical rainforests (Dennis and Westcott 2007) it might be expected that rainforest infestations will often be distributed in main and satellite populations. Consequently, when delimiting an infestation, searching beyond the apparent population boundaries is particularly important.

Blinking lights

A 'blinking light' represents a new satellite population established from seed dispersed from the main 'source' population. These populations may initially be transient unless they are replenished from the main source (that is, they blink on and off). A population blinks off permanently when it becomes extinct. A population's light stays on when it becomes self-sustaining and seed from it may spread to form new satellite populations.

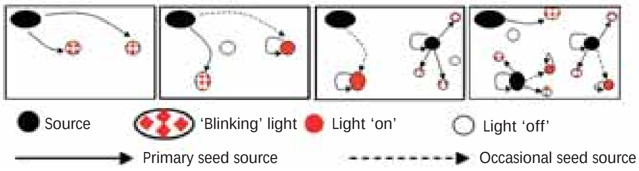


Figure 3: Blinking lights, sources and satellites.
Credit: H Murphy CSIRO

Rainforests in the landscape

Undisturbed rainforest is generally resistant to invasion by weeds and large intact stands tend to be devoid of introduced plants except at their perimeter (Goosem 2003). Weeds generally enter rainforest through edges (shade-intolerant species). However some species are brought into the system by dispersal agents (animals, water, natural disturbance events) and invade from within (shade-tolerant species).

Land clearing and human disturbance has resulted in fragmented patches of rainforest within a landscape. One of the most dramatic and well-studied consequences of habitat fragmentation is an increase in the proportional abundance of edge-influenced habitat. Converting continuous habitat into smaller discrete patches increases the amount of edge habitat, even if the total area of habitat is not changed. Effects of edges on the physical environment of patches, such as increased exposure to wind, sunlight and drying, are relatively well documented. Edge-affected zones as wide as 1 km have been reported for tropical forests, though most edge effects appear to manifest within 150 m in forest fragments (Laurance 2000). The changes wrought on the affected rainforest can make it more susceptible to invasion by weeds.

Forest fragments are also susceptible to 'bombardment' by seeds from weedy plant species in the surrounding vegetation. These may then be incorporated into the fragments' community (Janzen 1986).

In many tropical regions when forest is cleared for agriculture or pasture, strips of riparian vegetation are often left behind along watercourses to protect against erosion, and isolated trees are left standing to provide shade for stock or for aesthetic reasons. Free-standing trees in the surrounding matrix of tropical rainforest patches may be important perch sites for birds. Corridors, small fragments and even lone trees may serve as important stepping stones for pollinators and dispersers, increasing connectivity between larger patches of tropical forest. Because these isolated patches of vegetation become frugivore magnets they also become foci for the recruitment of both native and introduced species, facilitating weed movement within the landscape (Gosper et al 2005; Buckley et al 2006).

Some patches contribute more weed seeds than others

Identifying and directing weed control efforts to those patches of weeds or source populations that act as the greatest contributors to landscape spread is one way of strategically managing a weed population.

Trying to determine which populations act as the strongest source can be tricky. However, for fleshy-fruited species, fruit removal rates can be monitored at different sites to determine which sites are favoured by frugivores. This can act as a surrogate measure for dispersal. One study that compared rates of fruit removal of the emerging invasive, Mickey mouse plant (*Ochna serrulata*), a weed of bushland and rainforest habitats in the Brisbane area indicated that the rate of removal of fruits was greater in bushland than suburban habitats (Gosper et al 2006). The management outcome from this study was a recommendation that control in bushland habitats around Brisbane should be prioritised, but that suburban habitats were likely to act as significant seed sources for reinvasion and should not be ignored.

Summary point

Willson and Crome (1989) quantified the flux of native and exotic wind- and animal-dispersed seeds across a rainforest / field boundary in North Queensland. They found that both animal- and wind-dispersed field species' seeds (mostly exotic) were able to disperse up to 85 m into rainforest.

Source populations may vary in importance: fruits of the Mickey mouse plant are removed more quickly by frugivores in some habitat types than others.
Photo: C Gosper

A variety of landuses and features making up a tropical landscape:
1. Urban area
2. Urban forest patch
3. Contigueous forest
4. Large forest patch
5. Small connected patch
6. Small isolated patch
7. Corridor
8. Urban area fringing forest
9. River system
10. Road
Photo: Qld DNRMW

Social aspects of weed invasion

There are many pressures on rainforest habitats arising from the past and current social climate; some are obvious and complete (eg clearing for urban areas); some are more subtle (eg the proliferation of lifestyle parcels adjacent to rainforest). The majority of weeds in Australia have come from plants deliberately introduced for gardening, landscaping and agricultural production. For many gardeners in the tropics, tropical foliage and year round colour are a passion. Many gardeners achieve this by planting species from other countries with similar climates, such as Hawaii, Tahiti and South America, and local and national gardening shows promote tropical gardens which contain exotic species capable of being dispersed into adjacent rainforest habitats. Many of Australia's future weeds are currently growing in gardens, having yet to make the move from garden plant to weed.

A relatively recent trend has seen many Australians seeking rural lifestyles on the small parcels of land around and beyond the urban fringe. This dramatic urbanisation in rainforest regions is a cause for concern in terms of providing sources of infestation. Anecdotal evidence suggests that many buyers of these small land parcels and ‘lifestyle’ or ‘hobby’ farms have limited knowledge about natural resource management but have strong environmental values. Impacts on existing rainforest fragments and remnant vegetation through increased disturbance and a mixture of management styles and goals can degrade the ecosystem properties that were the initial drawcard. The sheer number of these lifestyle properties, such as the 2500+ individual blocks of land of mixed tenure and management along the 3000 km boundary of the Wet Tropics World Heritage Area (Setter and Vitelli 2003), means that they have the potential to significantly influence the dynamics of invasive species in a rainforest region. Furthermore, when owners sell their properties, these tropical gardens or private and commercial nurseries on the rainforest fringe are often left unmanaged and become source populations for weed spread. The increase in the number of urban gardens and the proximity of new developments to rainforest mean that they must become a focus of future weed management.

An emerging area needing careful consideration and management is when potential conservation conflicts emerge in situations where invasive species may be perceived as having positive and negative consequences (Buckley et al 2006). For example, some invasive species may reduce biodiversity of plant species in the habitats they invade, but at the same time support native fauna through provision of food and habitat (Gosper and Vivian-Smith 2006). Efforts to manage the invasive species must carefully consider the potential negative and positive ecological consequences of weed control interventions. It is also important to understand stakeholder views and to communicate how the benefits of weed management outcomes surpass the negative ecological consequences to the community when a specific intervention is implemented as a control measure.

The introduced flora of Australia and its weed status

Invasion is considered to be the least likely outcome of a multistage process that begins when organisms arrive outside their native range (Mack et al 2000). Williamson and Fitter's (1996) 'tens rule' holds that just one in ten of those species transported to a new location will appear in the wild (ie, become casual invaders); only one in ten of those casual invaders will become naturalised (manage to sustain a population over the short term); and one in ten of those naturalised will spread and establish invasive populations.

Many exotic species exist in very small numbers, for example in gardens and botanic gardens, and never become invasive. Determining why some species become invasive and others do not has long occupied researchers without many conclusive results. However, one of the most useful ways to determine if a species is likely to become invasive is its reputation elsewhere. The Weeds CRC recently published *The introduced flora of Australia and its weed status.* Every introduced plant species in Australia, past and present, is listed in this publication along with if, and where, it is 'weedy' elsewhere in the world. The publication aims to inform gardeners about potentially weedy plants that should be avoided.

*Miconia (*Miconia calvescens*): an escaped garden plant*

Miconia was first introduced in Australia to the Townsville Botanic Gardens in 1963 as seed from the Peradeniya Botanic Gardens in Sri Lanka (Csurhes 1998). The popularity of tropical foliage plants grew and by the 1970s plant nurseries in north Queensland were sourcing miconia plants mainly from Sydney, New South Wales and Tully, Queensland. Two naturalised miconia infestations were discovered in north Queensland around 1996 (Csurhes 1998), and to date 15 naturalised populations have been recorded there. All are in various phases of an eradication program.

The invasion of the Australian Wet Tropics rainforests by miconia poses a major threat to the World Heritage values of the area. This species is a serious invader in the tropical Pacific, including the Hawaiian and Tahitian Islands, where it forms extensive monocultures and dense thickets that have taken over large tracts of rainforest habitat. Miconia, sometimes called 'the green cancer' in French Polynesia or 'the purple plague' in the Hawaiian Islands, is considered by scientists and land managers to be the worst pest plant in these two Polynesian archipelagos and potentially the most damaging weed of rainforests of Pacific Islands. It is estimated that the planting of a handful of miconia trees in Hawaii for ornamental purposes in the 1960s has the potential to cost several billion US dollars. This cost is based on loss in revenue, stemming from a loss in biodiversity, increase in runoff and sedimentation, reduction in groundwater recharge and damage to infrastructure. Miconia has thrived and spread to all the wetter habitats on Tahiti and now covers approximately 65 % of the island after a single specimen was introduced to the Papeari Botanical Garden in 1937.

Miconia growing in a hanging basket in a garden in Cairns.
Photo: M Blackwell Biosecurity Queensland

The logistics of weed management in rainforest

Weed management guides are often devised under the assumption that invasives are readily detectable and that the major limitation on control is the resources that can be dedicated to their eradication. The reality of tropical forests is starkly different. Particularly at their early stages, infestations in tropical forests can be difficult to delimit (ie find and determine the spatial extent) due to the structural and taxonomic complexity of the habitat. Even the delimitation of a high density infestation may be difficult, while the detection of a satellite infestation can present a major challenge. Difficulty of detection means that neither reducing seed dispersal from larger source populations, the power behind the establishment of new satellite infestations, nor the establishment or rate of spread of satellite populations can be ignored since both can continue to contribute to 'invisible' spread.

Searching for new infestations and delimiting the extent of existing infestations is particularly difficult in rainforest habitats because the high native species diversity and vegetation density mean that this usually cannot be done from the air. In fact, even on the ground a person often has to be within a few metres before a plant can be seen. Similarly it is difficult for on-ground crews to distinguish new problem weeds from native species at an early stage. The lack of a management presence over large expanses of rainforest habitats also means that early detection of small weed populations is unlikely unless the species is particularly targeted. When weeds are identified, control operations must often be done on foot and by manual methods for weeds occurring inside rainforest. Broad-scale herbicide use is usually not an option in or close to rainforest; nor has biocontrol proven particularly successful for rainforest invaders.

Summary point

The efficiency of search and eradication efforts in rainforest habitats is severely hampered by dense vegetation, high species diversity, difficult terrain, trying climatic conditions and remoteness of much of the area from vehicle access.

Lantana (*Lantana camara*) and biocontrol

Lantana would be considered one of the most aggressive weeds entering Australia. To date, managers have considered a variety of approaches including fire, chemical application and biological control (biocontrol). Biocontrol options often become attractive when the invasive species has become so widespread that on-ground efforts alone become unrealistic to achieve control. For lantana, biocontrol efforts began in Australia almost 100 years ago and have been extensive, with more than 20 agents introduced. The complex breeding of this plant with its many hybrids and biotypes is thought to be one factor hindering success. However, research has provided opportunities to understand key interactions between weedy plants and dispersers, enabling future management programs to consider all plant / animal interactions occurring within a particular landscape system.

For example, the fruit- and seed-damaging fly *Ophiomyia lantanae* is a widespread biocontrol agent introduced into Australia for its ability to infest lantana fruit and seed. Research indicates that while the fly does cause some damage to seeds and fruit, making the fruit less attractive to dispersers and affecting germination processes, the different lantana biotypes respond differently to this pressure. Overall the researchers concluded that the magnitude of the responses measured was unlikely to greatly influence plant densities of lantana in south-east Queensland infestations (Vivian-Smith et al 2006).

3. Principles for the strategic management of weeds in rainforest

‘Resilience’ is often described as the capacity of a system to undergo disturbance and still maintain its functions. A complementary notion is that of ‘resistance’; the ability of a system to be proofed against disturbance. For example, a patch of habitat might be considered resistant to invasion if it remains relatively uninvaded over long-periods of time despite high external pressure from surrounding land-uses. On the other hand a patch would be considered resilient if, despite becoming invaded, there is no significant change in its native species diversity, ecological function or some other ecological value. Resilience and resistance are useful concepts for considering ecological objectives for weed management in rainforests.

The strategic principles proposed here have three overarching goals:

1. reduce the threat of weeds to rainforest habitat
2. create resistant habitat
3. manage for resilient landscapes.

These principles will be most useful when coupled with a sound knowledge and understanding of a given landscape. Building this knowledge will take time, though a good deal of knowledge about the landscape context of particular invasions already exists in a variety of (often disconnected) forms and should be compiled in such a way as to inform the principles and translate them into strategic management guidelines.

Most of the principles proposed here will eventually lead to a reduction of weeds and to more resistant and resilient landscapes. However, strategic plans are by definition long term and many of the principles suggested will necessarily involve time-lags between management actions and their consequences.

Summary point

A strategy is adaptable rather than a rigid set of instructions, and is a long-term plan of actions. Strategic plans need to be adaptable, take account of potential time-lags, and anticipate future scenarios and circumstances.

Managing single species, multiple species and landscapes

Introduction of invasive species in tropical systems has far outpaced the ability of researchers and managers to study the consequences of each invasion, develop management strategies or implement control for every established species (Radosevich et al 2003; Marvier et al 2004). Furthermore, ecological information on invasive species is often incomplete, not quantitative, or not relevant to its invaded range (Mack 1996). A range of strategies are necessary for management of invasives in rainforest habitats; including focused management of high-risk single species, strategies that target suites of species, and strategies that target entire landscapes.

A single-species approach to invasives management is often necessary for high-risk species such as those targeted under national eradication programs or for WoNS species. Focusing on these disproportionately high-risk or high-impact species also provides benefits through identification of important processes of invasion that can then be applied to other species (Lindenmeyer et al 2008), and through management actions that opportunistically target other invasive species. Single-species tactics however, should still be considered in terms of the strategic level principles described further along.

Landscape-level management of invasive species necessarily involves consideration of multiple species. However, invasive species in tropical regions are highly diverse and are characterised by a variety of life-history traits, growth forms and seed dispersal vectors. Classifying species into functional groups allows consideration of the effects of management on groups of species that can be expected to respond in a similar way (Gosper et al 2005). The question is which functional classification is the most useful for predicting ecological impacts and responses to management? Functional classification of native rainforest species is usually made on the basis of shade tolerance and regeneration strategy and species are classed as either pioneers or non pioneers based on some combination of morphological or ecological traits (Köhler and Huth 1998; Slik 2005). Life-form is also a key functional trait. Given the key role of dispersal in landscape-level population dynamics, consideration of the attributes influencing the primary dispersal agent or mode (eg adaptations for particular modes of dispersal or to attract particular dispersers) in any functional classification would seem necessary (Westcott and Dennis 2003; Westcott et al 2008a). For example, many management strategies will be similar for woody, fleshy-fruited species, for wind-dispersed herbaceous species, or for tropical vines, although the method for on-ground tactical control might be quite different.

Rainforest habitats of eastern Australia are embedded in multi-use landscapes with a variety of ecological, social and economic values. Rainforests occur as very large swathes of habitat as well as patches of all shapes and sizes surrounded by highly modified land-uses, sometimes connected by corridors of habitat. It is important to remember that the area of a particular habitat type rarely reflects the amount of suitable habitat for a given species. Furthermore, habitat for some species is strongly associated with extensively modified landscapes characterised by long-standing human use (Lindenmeyer et al 2008). However, patch-based habitat management is the norm in multi-use landscapes. The problem is that even if a single patch is subjected to intense management of invasives it may still degrade if the surrounding landscape continues to contribute to the problem. Patches need to be assessed and managed within the context of the landscape mosaic and the interactions among patches and the surrounding matrix (Lindenmeyer et al 2008; Murphy and Lovett-Doust 2004).

Reducing the threat of weeds to rainforest habitats

The first step in reducing seed sources and dispersal potential is to identify populations that may contribute disproportionately to the tail of the long-distance dispersal curve (see Figure 2), and major source populations or populations at risk of becoming sources. These should then become a priority for control.

Managing long-distance dispersal

For wind- and water-dispersed species, it may be more important to contol 'upstream' populations regardless of their size since they may contribute more to long-distance dispersal. For example, for water-dispersed species, targeting upstream populations in a catchment before spending time and resources on downstream areas will greatly reduce the probability of reinfestation of downstream areas following control. Similarly a large population of a wind-dispersed invasive species located on the side of a hill or on a major transportation easement might contribute disproportionately to seed dispersal.

Dispersal 'highways'

Major roads and rivers may serve as dispersal highways for weed seeds allowing long-distance transport of a high volume of seeds. For example, population A of a fleshy-fruited woody weed is located in a riparian area a short distance away from another riparian network which has connectivity to large patches of weed-free habitat. Population B of a wind-dispersed species is located on a major transportation corridor close to a divergence leading to currently weed-free patches of habitat. Both populations are important sources located on the equivalent of dispersal 'highways', and have the potential to contribute to the tail, or long-distance section, of the dispersal curve and form new satellite populations. Populations with characteristics like those of A and B should be considered priorities for control.

Figure 4: Prioritising control of source populations on dispersal 'highways'. Credit: Qld DNRMW

Managing large, upstream populations of species capable of spreading long distances by water is clearly a priority. Reducing connectivity between different drainage networks where possible (eg by use of fencing when networks are separated by grazing landuse and when cattle are dispersal vectors) as well as targeting potential source populations for control, may be effective in some circumstances, particularly when drainage networks are located relatively close together. Backflow of floating seeds up drains and creeks during flooding may also increase dispersal of some species (Swarbrick 1993). Anticipatory management of these potential avenues of dispersal such as through restoration of natural levee banks to reduce overspill, may reduce the probability of immigration upstream. However, it should be remembered that secondary dispersal modes, such as dispersal by animals, may move propagules across these barriers producing patterns of spread that are unexpected (Westcott et al 2008b).

Control practices could be prioritised for populations located in areas more heavily utilised by potential long-distance dispersers. For example, cassowaries in North Queensland are the primary biotic dispersers of the invasive pond apple (*Annona glabra*). Cassowary dispersal can be long distance and differs from the dominant water dispersal mode in that cassowary-dispersed infestations can be established up-stream from the source infestation, or even across drainage boundaries and into previously weed-free drainages (Westcott et al 2008b). Control of pond apple populations in areas heavily utilised by cassowaries, including in corridors of native vegetation within the matrix, would serve to reduce propagule pressure at the long-distance tail of the dispersal curve.

The prevention of the spread of weed seeds via movement of people and vehicles is a crucial element in containing long-distance dispersal. This will primarily be managed through education and awareness of these pathways of weed spread and the availability of suitably placed wash down facilities. The Queensland Weed Spread Prevention Strategy 2002–2006 and the Far North Queensland Regional Organisation of Councils Regional Weed Spread Prevention Strategy (2007–2009) outline actions for minimising the spread of weed seeds.

Managing sources and satellites

Resources for prevention and control of invasive species are finite, making decisions about where to direct resources an important consideration. Ecological theory suggests prioritising control of large populations, because these supply the majority of seeds at a regional scale. Furthermore, in tropical rainforests where logistics make searching for isolated populations or individuals resource intensive, these are the easiest populations to locate and delimit. Researchers also agree that early in the invasion ‘offensive’ tactics (that is preventing spread from invaded areas) reduces overall population growth. However, the results of some models highlight the importance of eradicating small outlying populations, or satellites, since these contribute the most to range expansion (Moody and Mack 1988; Higgins et al 2000) and eventually become sources themselves (see Figure 3). Research has also shown that later in the invasions process after many areas are already invaded, ‘defensive’ tactics, that is preventing spread to uninvaded locations, reduces overall spread rates (Drury and Rothlisberger 2008).

When developing strategies for prioritising control of sources and satellites consideration should be given to the:

(a) functional type of weed, particularly the capacity for long-distance dispersal

(b) stage of invasion

(c) resources available.

As a general rule, current research indicates that if an invasion is in the early stages and resources are limited, and when short-distance dispersal predominates, management should target high-density, or source populations. At later stages of the invasion, and particularly when long-distance dispersal is common, more resources should be invested in

Management of an interacting invasive species and endangered native species

The situation where an endangered native species, the cassowary, acts as a primary biotic dispersal agent in the spread of a noxious weed such as pond apple makes for a tricky management situation. While on the one hand managers seek to eradicate an aggressively spreading weed, some in the community see the weed as an important and favoured food source for an endangered species. However, any perceived conservation benefit is bestowed at a distinct cost to cassowaries. While pond apple provides a plentiful resource for several months of the year, it often forms mono-specific stands at the cost of a diverse native flora. A diverse flora provides a number of benefits over pond apple dominated stands. First, a diverse diet is more likely to be nutritionally complete than one dominated by a single food species. Second, a diverse flora is better buffered against bad seasons as a greater range of environmental tolerances is represented. Thus cassowaries feeding in native vegetation types are less likely to face a starvation year than those in a pond apple dominated stand.

Nevertheless, management of pond apple must also consider the needs of cassowaries. Due to the restricted and fragmented nature of cassowary habitat in coastal areas of the Wet Tropics, complete pond apple removal may (at least temporarily) be detrimental to some cassowary populations. Control programs should include revegetation with appropriate cassowary food plants, and perhaps staggering control efforts over time.

satellite populations regardless of the amount of resources available. Of course, most control and eradication programs include a mix of source and satellite control. However, Figure 5 illustrates where the higher proportional investment should be directed. Each weed species or group of weed species should be assessed in terms of each of the axes.

Prioritising investment to control weeds

Deciding on when to put more resources into managing sources or satellites depends on the stage of invasion (early or late), the predominant dispersal distance (short, local or long distance) and what / how many resources are available for management.

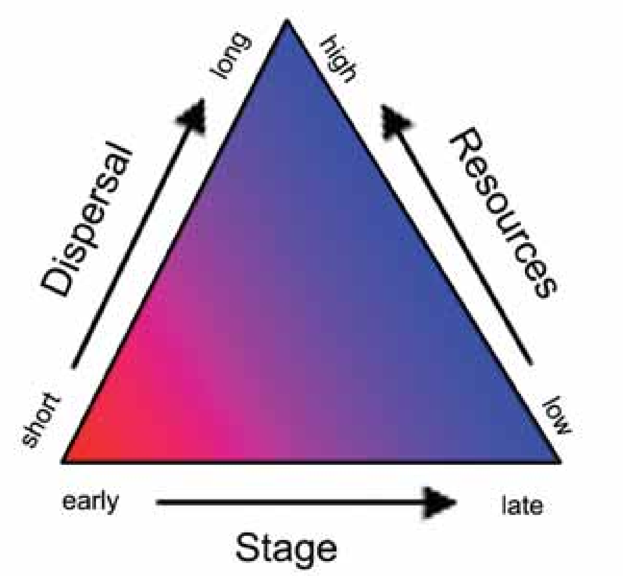
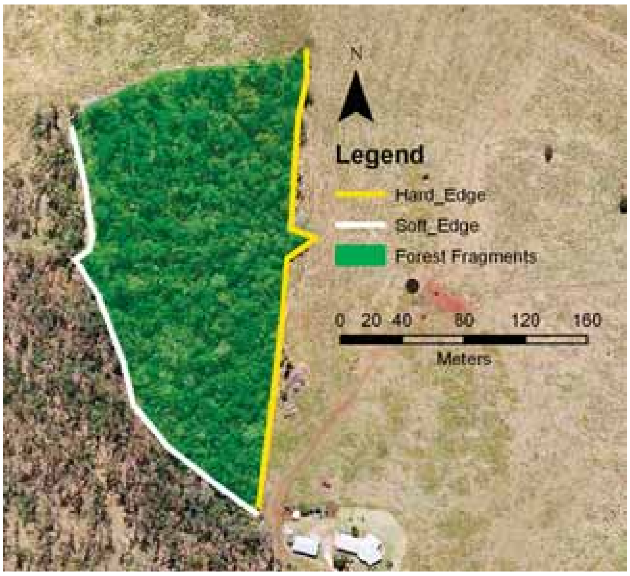


Figure 5: Prioritising control of sources and satellites.
Red: prioritising source populations
Blue: prioritising satellite populations
Credit: H Murphy CSIRO

Creating resistant habitat

Managing edges

Edges may be considered the point of entry for external influences such as invasion by exotic species (Cadenasso and Pickett 2001). To minimise exposure of native habitat patches to these external influences, the obvious approach, and the first step in management, is to minimise the ratio of patch edges to interior. Minimising edge:area ratios can be achieved in several ways. First, larger patches have a lower edge:area ratio. Maintaining large, continuous patches of habitat, and minimising fragmentation of existing large patches, reduces the effect of edges. Second, circular or square patch shapes have the lowest edge:area ratios; the more irregular the patch shape is, the greater the edge:area ratio and the more interior habitat is influenced by edge

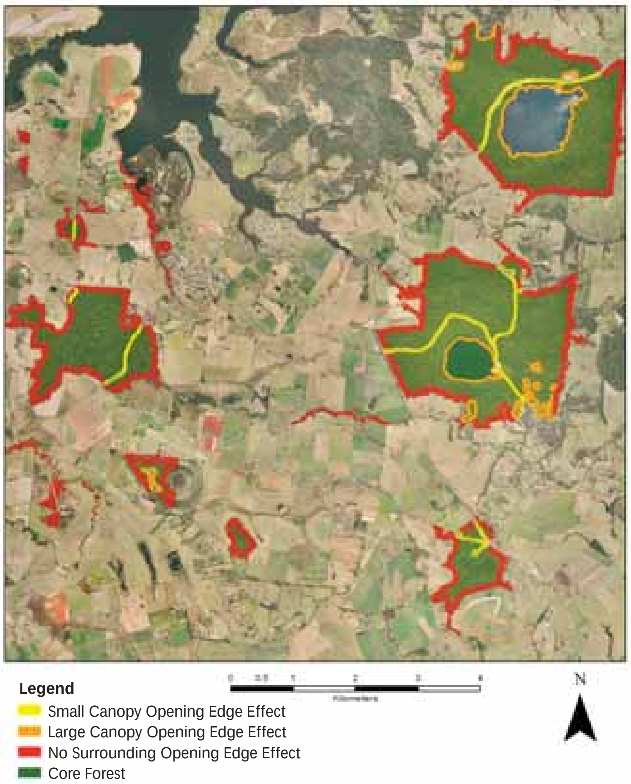


'Hard' and 'soft' edges surrounding rainforest fragments.
Photo: Qld DNRMW

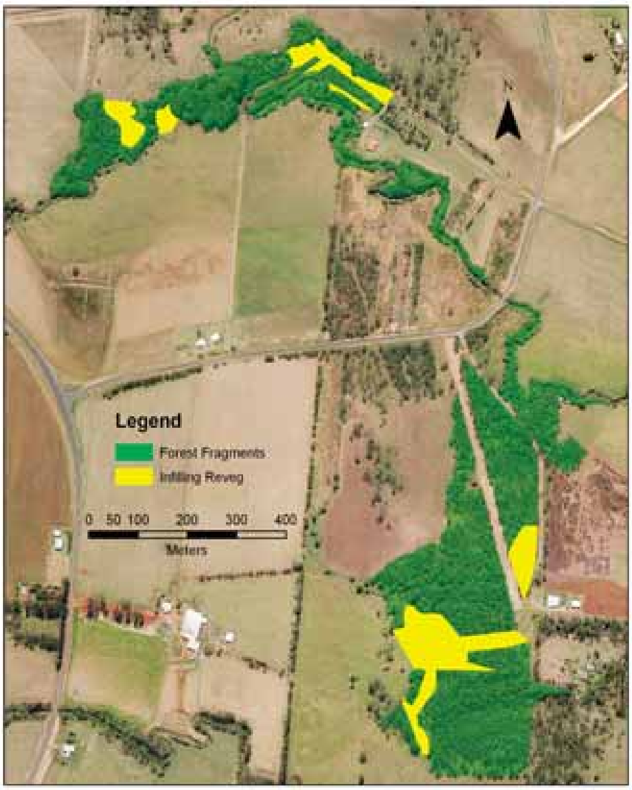
effects. Realistically, once a landscape is fragmented it is difficult to influence patch edge:area ratios other than through strategic revegetation involving infilling of gaps or through the creation of buffers. Infilling, particularly of linear disturbances in fragments has a significant impact on edge:area ratios.

Field research indicates there may be some advantage to management aimed at decreasing permeability of edges to key dispersers of exotics (Cadenasso and Pickett 2001) and to the physical influences that modify edge habitat, ie, edge 'sealing' (Harper et al 2005). Forest edges are favoured feeding sites for many frugivorous birds, and plants there may have more rapid removal of their fruits (Galetti et al 2003). Edges are also the favoured route for movement of some disperser species (Levey et al 2005) and consequently might be expected to be subject to increased seed deposition. Edge-related gradients in biophysical variables (such as light, heat and wind) are also likely to be less pronounced when the adjoining habitat is more similar in structure to that of the fragment.

Rainforest patches may have an impenetrable boundary that some dispersing individuals never cross and in which native species never recruit, ie a 'hard edge' such as the boundary between a cane field and a rainforest patch. Or they may have a barrier that is very permeable to dispersers where recruitment of natives is possible, ie a 'soft edge' such as between a mature forest patch and regrowth forest (Stamps et al 1987). Maintaining soft edges as a buffer around rainforest patches will minimise the likelihood of weeds permeating rainforest patches.



Patches of different sizes and edges with a 100 m buffer (shown in red). Edge effects around small patches of rainforest leave little 'core' or unimpacted forest remaining. Fragmentation of patches from roads and infrastructure also creates internal edges (shown in yellow). Small openings of the canopy from minor roads may only impact the edge over shorter distances, compared with larger, internal disturbances for car parks, buildings etc.
Photo: Qld DNRMW



An example of where revegetation infilling (in yellow) would reduce the edge:area ratio of irregularly shaped patches.
Photo: Qld DNRMW

Where tropical forest remnants are embedded in agricultural land in which burning or the application of herbicides is routine, the sustainability of the fragments is at risk because the forest is unable to regenerate at the edge or to buffer its interior. In this case, one management strategy which minimises the influence of edges on natural forest habitats is to create and maintain buffer areas. These buffer zones can be managed to resemble a natural ecotone allowing a transition from forest to matrix habitat, rather than an abrupt edge (Gascon et al 2000). In areas where matrix habitat is more similar to the native habitat, most edge effects will either remain stable over time or decrease as vegetation

Native plant buffer strips and 'soft edges' for weed control in tropical rainforests

Habitat fragmentation often causes 'hard' edges between natural and human environments. In rainforest ecosystems this leads to a break down in the natural buffering ability of dense rainforest canopies and consequently provides suitable habitat for light-loving weedy plant species. The restoration technique of buffer-strip planting provides a tool to reduce weed incursions in fragmented rainforests as these plantings aim to reduce the harshness of edge transition zones and re-instate the rainforest canopy's natural buffering ability.

In 1993, a 30 m to 40 m buffer strip of native rainforest species was planted along the perimeter of the Malanda Scrub (Mabi Forest) and the Malanda Falls Scenic Reserve. Research evaluating the success of these plantings shows a reduction in the overall abundance of weeds along the restored rainforest edges and subsequent protection of the interior remnant from further weed invasions. These results imply planted buffer strips successfully 'soften' edge transition zones between the remnant rainforest interior and the surrounding human-created environment and provide a suitable tool for reducing weed abundance in tropical rainforest fragments (Laura Sonter, University of Queensland Honours Project 2008).

regenerates along a fragment's edge (Gascon et al 2000). In such cases, normal forest succession occurring at the edge may at least achieve a balance between exposure and regeneration, where the interior of the fragment is buffered and retains most of its primary forest character (Gascon and Lovejoy 1998).

Summary point

Managing vegetation structure at edges to minimise the impact of changes in physical conditions, in conjunction with removal of exotics from edges, will reduce the spread of invasive species into interior habitat.

Managing the matrix

Isolated, standing invasive trees planted or established in human-managed landscapes should be removed since research suggests they may contribute disproportionately as sources of seed within the landscape. However, their role as landscape connectivity elements for dispersal of native species first needs to be carefully considered. Where these individuals serve as perching sites for birds or are utilised by other vertebrates for foraging or as stepping stones, they should be replaced with appropriate native species and in the short term with structures, which could be the tree itself killed but left standing, to encourage continued use by dispersers of native species. In addition, research on the contribution of isolated standing native trees in highly modified habitats (as discussed earlier) suggests that they may contribute significantly to patterns of succession in nearby patches of rainforest. Planting native trees of early successional species in cleared land, or preferably leaving mature trees when clearing occurs, close to forest fragments, may help accelerate succession in forest fragments, since these trees have been shown to contribute disproportionately to recruitment (Aldrich and Hamrick 1998; Carrière et al 2002). Windbreaks can also significantly increase the deposition of native tree and shrub seed in agricultural landscapes in tropical regions (Harvey 2000). To the extent that these sites become foci for seed deposition they should also be targets for weedy plant search and eradication efforts.

Summary point

Identifying key landscape elements in the matrix that contribute disproportionately to dispersal is an important step in creating resistant habitat.

Managing succession

Suitable patches for most non-native species in tropical forest habitats typically exist only early in succession following disturbance and the older a patch is the higher the extinction rate of the invasive population. This suggests that if succession can be accelerated, the time to extinction of an invasive population can be shortened (Johnson 2000; Boughton and Malvadkar 2002).

Controlled succession involves manipulating:

- disturbances, to create or eliminate site availability for particular plant species
- colonisation, to decrease or enhance availability and establishment of specific species
- species performance, to decrease or enhance the growth and reproduction of particular species (Sheley and Kreuger-Mangold 2003).

Some researchers have recently demonstrated augmentative restoration techniques for accelerating succession in natural systems (Bard et al 2004). Fast-growing ‘framework’ species are often used in revegetation programs to provide a leafy, closed canopy within 12 to 18 months. The purpose of these plants is to quickly shade out weed species and provide a framework under which shade-tolerant native species can establish. These framework species also provide perching sites and a bait crop to entice seed-dispersing animals from adjacent areas and so accelerate the establishment of other species and life-forms. In tropical systems, sites rehabilitated using suites of fleshy-fruited native species from different stages of succession have been shown to significantly accelerate colonisation by a range of other species of a variety of life-forms (Tucker and Murphy 1997). However, deposition of invasive plant seeds can also be high beneath these replantings (Buckley et al 2006) and these may become foci of invasive spread (With 2002).

Summary point

Management principles for creating resistant habitat are intended to reduce the impact on rainforest habitat from many invasive species at once. However it may be simpler for managers to consider creating resistant habitat in the context of preventing impacts from a single invasive species; resulting management actions may then target other invasive species. This is a similar approach to that of ‘umbrella species’ used in conservation management strategies, where species are chosen as targets for conservation because their conservation requirements are believed to incorporate the needs of other species (Lambeck 1996). So decisions concerning land management, eg habitat size, distance from other communities and risk from threatening processes, are based primarily on one species and in doing so the needs of other species present are automatically met.

Replanting sites, natural succession and weed invasion in sub-tropical habitats

Restoration and replanting programs often aim to 'jump-start' natural successional processes and by-pass some of the early stages. However the speed or direction of the process cannot always be predicted particularly when weed invasion takes place.

A study which measured seed deposition and establishment patterns of native and weed species in sub-tropical sites where replantings had occurred, and in sites without restoration interventions, has highlighted how different processes operate at these sites (White et al 2008). Sites with restoration interventions (native plantings) had fewer weed seeds being deposited, but they had a disproportionate number of weed species recruiting at these sites, suggesting they provided conditions that were particularly suitable for the recruitment of weeds over native species. On the other hand, sites without restoration interventions (regrowth dominated by camphor laurel) facilitated recruitment of more native and weed species than would have been predicted by the seed deposition patterns alone. This highlights that in natural and accelerated successional habitats a range of management approaches need to be carefully designed, that differentially promote the establishment of native species over weeds (and the desired successional trajectory) taking into consideration the different processes that may be taking place.

Managing landscapes for resilience

Managing weed response to disturbance

Predicting species' responses to disturbance has been a major focus of ecological research. Although targeting management efforts against the specific invasive species makes sense, in many cases invaders are opportunists that take advantage of environmental mismanagement and degradation (ie they are passengers to disturbance). Under such circumstances, efforts to manage invasives may be repeatedly frustrated while the underlying environmental problems remain unresolved (Hulme 2006).

There is a wide range of exotic species which are long-lived plants or persistent annuals that have the capacity to alter the long-term successional trajectory of a site (see Cyclone disturbance to North Queensland rainforest and Persistent invaders—'strangled gaps' in rainforest). Their control should be a top management priority, as should research aimed at understanding the system attributes that promote their invasion or are altered by them as they establish.

Persistent invaders—'strangled gaps' in rainforest

Giant bramble (*Rubus alceifolius*) is a fleshy-fruited, shade-intolerant, non-native scrambling shrub capable of smothering other plants and forming dense thickets. Bramble thickets are relatively common in the rainforest of the Wet Tropics, often covering large expanses. Rapid growth of scrambling species and vines post-cyclone disturbance has been shown to inhibit recruitment of native species, creating the phenomenon of 'strangled gaps' in tropical forests (Horvitz and Koop 2001). The species may persist for tens to hundreds of years, consequently retarding the succession response of native species and dramatically altering the structure and composition of the forest in the longer-term.

Measuring rainforest and weed seeds deposited in regrowth dominated by camphor laurel.
Photo: G Vivian-Smith QDPI&F

Giant bramble patch smothering rainforest with only a few emergent trees.
Photo: T Sydes Biosecurity Queensland

Pro-active planning for weed management following cyclones

Natural disturbances shape rainforest habitats. Extreme natural disturbances can have profound effects, and are difficult to predict and manage. Rather than allowing extreme events to drive management responses, they can be anticipated and appropriate responses are likely to be much more effective if planning is done.

Besides creating ideal conditions for weed regeneration due to higher light levels in the understorey, the clearing of roads and easements of debris and restoring of services following cyclones is a major operation resulting in an influx of resources, heavy machinery and equipment from across and outside the region. Spread of weed seeds in these circumstances is highly likely, given that the urgency of the operations means usual weed hygiene measures are a low priority and that operators unfamiliar with the area and its weeds are often called in. Having a plan in place with the goal of quickly and efficiently disseminating information is an important step in containing the potential longer-term impact. The Far North Queensland Regional Organisation of Councils has prepared a local government disaster management code of practice to help prevent the spread of weeds during natural disasters such as cyclones and flooding.

Weed management itself creates disturbance through mechanical removal, herbicide use, soil disturbance, track creation etc. Management plans that include weed removal are often not linked to a post-removal revegetation plan. The regeneration consequences of control actions should be examined and incorporated in management strategies in order to prevent the creation of a ‘weed-shaped hole’, ie post-control reinvasion by the same invader or another disturbance adapted invader (Buckley et al 2007). On the other hand, revegetation in tropical landscapes is often managed with the goal of minimising impacts from weeds as the vegetation grows. This knowledge and experience can also be used to manage natural habitat following weed control. Impacts to rainforest habitat from activities associated with weed control should be carefully considered and planned for.

Summary point

If weed establishment is enhanced by disturbance, then weed management may create a ‘weed-shaped hole’ providing ideal conditions for re-invasion by the same or another invasive species (Buckley et al 2007).

Debris on roads following Cyclone Larry.
Photo: A McKeown CSIRO

Whole-of-system and scale-appropriate management

The development of strategic responses to invasive plants is not a simple task and requires that the problem be dealt with from a systems perspective. First, this entails that a whole-of-system response is adopted. That is, incorporating as many of the relevant ecological aspects of the invasive species and native ecosystem as possible and of the human dimension of the problem. This latter point is important because though biological invasions may be the manifestation of ecological processes, it is in the human domain that their impact gains its relevance and from which both the impetus and the limits for their management are derived. Human dimensions have a huge impact on whether management is begun or is successful. They are no less varied than the ecological dimensions and include social, economic and institutional considerations. Second, the response must be scaled appropriately. Ideally this means that management incorporates the entire area of the known infestation, and the likely range of dispersal around this. Appropriate scaling also requires that management and its follow-up are viewed and funded in timeframes that incorporate time lags for the location of missed populations and for known seedbank longevity. Third, biological invasions are essentially a process of spread through a landscape. Thus management resources and effort must be aimed at containing this spread and then at reducing abundance within the infested area.

The focus of most current management effort is squarely on tactical responses; the eradication of a species from a particular location and how best to achieve this. Tactical responses are fundamentally important to the management of invasives as they are, after all, how individual plants are destroyed. However, success is dependent on recognising that individual infestations are just a fragment of the problem. Success in removing a species from one site will be of limited value if nothing is done about the infestation on the property next door. Consequently, it is important that, wherever possible, management efforts are scaled to the range of the problem. For example, if a weed is restricted to a catchment, then resources and effort should be coordinated across that catchment in a manner that maximises the probability of its eradication or results in the greatest reduction in spread by targeting the locations that are most likely to contribute to this.

Summary point

Because a single strategic framework for managing an entire plant invasion is likely to be complex and unwieldy it will usually be necessary to adopt components of the management plan at different scales. For example, many of the institutional and economic decisions will need to be considered at the scale of the range of the species. Inconsistencies in legislative arrangements for species whose ranges span state boundaries can undermine regional management actions so communication and collaboration across state boundaries should be incorporated in strategic management frameworks. Decisions about which infestations to manage, and which resources to deploy and when, will be made at the landscape or local scale.

Far North Queensland Regional Organisation of Councils—Strategic management of weeds

Pond apple is a Weed of National Significance (WoNS) and is a major environmental weed of the Wet Tropics bioregion, covering around 2000 hectares of land. Six local councils across the infestation area have been controlling pond apple with various levels of intensity since 2004. The Far North Queensland Regional Organisation of Councils (FNQROC) in partnership with Terrain NRM recently facilitated a coordinated approach to pond apple control across the local shires through a strategic management project.

Strategic control of pond apple infestations has seen activities initially target upstream areas (or source populations), since pond apple seeds are dispersed primarily by water, so that when control is initiated in heavily infested downstream areas replenishment is less likely. Another strategy incorporates the revegetation of heavily infested areas that have been treated, reducing the ‘weed-shaped hole’ effect and the likelihood of reinfestation.

The project has forged new partnerships between traditional owners, private land holders and state and local government officers, which greatly enhanced control outcomes through cooperative arrangements.

Conclusion

Currently, invasion by weed species represents a significant and increasing threat to tropical forest habitats. Management actions which consider the regional- or landscape-level ecological context of an invasion are likely to be more effective against the establishment and spread of weeds than a locally-focussed species-by-species approach.

Fostering a culture of collaborative management and research, and pooling of resources including expertise, is the only way to achieve management outcomes at the landscape or regional scale.

Staff from Biosecurity Queensland, Queensland Parks and Wildlife Service, CSIRO and Douglas Shire Council participating in the annual 'Melastome Taskforce' during WeedBuster Week 2007.
Photo: D Hardesty CSIRO

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